Aircraft Hydraulic Systems Handbook – Overview

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Hydraulics Systems Handbook

- **What is it?**
- **Who is the beneficiary ?**
- **Who complied it?**
- **What is the status of this Handbook?**
- **What are the topics discussed in this order?**

What is it ?

- **Currently we frequently use referenced industry documents like; {SAE AIR, ARP, AS, MIL-STD, etc.} during hydraulic system certification**

- **Most of the technical information are extracted from existing FAA documents such as Regulations, TSO, ACs, Orders, certification projects, and industry documents. There is no single reference guide to hydraulic systems related information**

- **This order (Handbook) offers guidance on certifying and maintaining hydraulic systems for aircraft. It applies to hydraulic systems for all aircraft categories (from normal category helicopters, small airplanes to large transports).**

Who is the Beneficiary?

- **This order is for engineers and inspectors in the Aircraft Certification Service and Flight Standards Service. It is also for persons designated by the Administrator (DER) and organizations (DOA & DAS) associated with the certification processes required by 14 CFR Part 183 and Part 21 Subpart J and M**

- **If you are a FAA systems engineer or inspector, this order will help make your aircraft hydraulic system certification and operational project successful. In it, we tell you which regulatory guidance to apply to your project.**

Who compiled it?

The Handbook team members are:

- **Les Taylor, Small Airplane Directorate**
- **Uday Garadi, Rotorcraft Directorate**
- **Werner Koch, Airplane Certification Office**
- **Mahinder Wahi, Transport Airplane Directorate**
- **Lee Nguyen, Aircraft Certification Service**
- **Frank Wiederman, AFS-300 Flight Standards Service**

What is the status of this Handbook?

- **Completed disposition of FAA comments – 5/11/05**
- **Completed union review – 5/11/05**
- **Submitted for legal review – 5/12/05 (Legal has not yet reviewed document)**
- **After legal review is completed, issue Order 8110.X Aircraft Hydraulic Systems Handbook**

What are the topics discussed in this order?

- **This order is a tutorial document for hydraulics systems and applying them to civil aircraft. It gives details and requirements for designing, making, and testing hydraulic systems, including components, complete systems, and their installations. Testing includes qualifications tests, acceptance tests, installation and assembly tests, aircraft hydraulic system simulator, flight tests, and functional tests.**

- **we discuss how to apply hydraulic energy, and why and how to use it on civil aircraft. This order also offers guidance on system safety assessments (SSA), instructions for continued airworthiness (ICA), maintenance, inspection, reporting requirements, and lessons learned.**

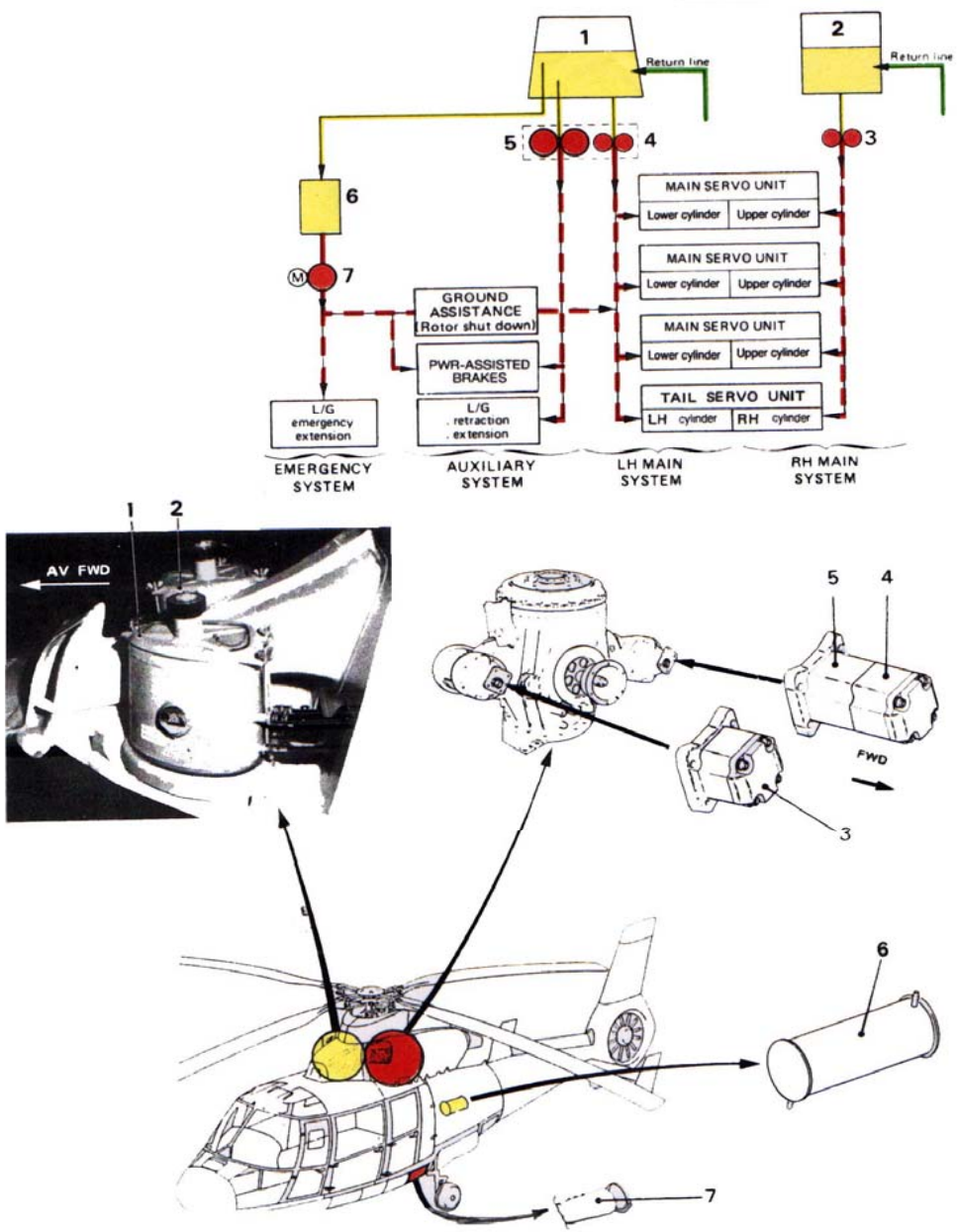
Handbook Table of Contents

Typical Hydraulic System

- **Components may include:**
  - **Actuators (servos) on each flight control**
  - **Pump, usually driven by main engine gearbox**
  - **Reservoir to store hydraulic fluid**
  - **Switch in cockpit to turn system off**
  - **Pressure indicator in cockpit to monitor system**

1. LH hydraulic reservoir
2. RH hydraulic reservoir
3. RH hydraulic pump (gear type)
4. LH hydraulic pump (gear type) coupled to the auxiliary pump
5. Auxiliary hydraulic pump (gear type)
6. Emergency hydraulic reserve
7. Emergency electric pump

Note the different suction levels of the three systems on the LH hydraulic reservoir.



Hydraulic Systems in Rotorcraft

- **Most helicopters use hydraulic actuators to overcome high control forces**
- **Small helicopters use hydraulic actuators to prevent vibrations from being transmitted from rotors to the control stick**
- **When servo activated, it provides an assisting force to move the respective flight control**
- **If hydraulics fail, can control aircraft, but control forces heavy**
- **If manual operation not possible, need dual independent system**

CHAPTER 2. SYSTEM DESIGN

SECTION 1. ELEMENTS THAT MAKE UP A HYDRAULIC SYSTEM

1. HYDRAULIC FLUIDS
2. HYDRAULIC FLUID CONTAMINATION
3. SYSTEM DESIGN OPERATING PRESSURE (DOP)
4. PROOF AND ULTIMATE (BURST) PRESSURE REQUIREMENTS
5. PRESSURIZING THE HYDRAULIC RESERVOIR

SECTION 2. HYDRAULIC SYSTEM DESIGN

1. GENERAL SYSTEM CHARACTERISTICS
2. COMPONENT DESIGN CONSIDERATIONS
3. HOW AND WHERE TO GET HYDRAULIC SYSTEM COMPONENTS

CHAPTER 2. SYSTEM DESIGN (Cont'd)

SECTION 2. HYDRAULIC SYSTEM DESIGN (CONT'D)

4. TYPICAL HYDRAULIC COMPONENTS
5. IN-SERVICE HYDRAULIC SYSTEM PROBLEMS
6. SYSTEM DESIGN CONSIDERATIONS
7. FLY-BY-WIRE FLIGHT CONTROL SYSTEMS
8. HYDRAULICALLY POWERED FLIGHT CONTROLS FOR HELICOPTERS
9. EVALUATING FATIGUE OF ROTORCRAFT FLIGHT CONTROL ACTUATORS
10. SCHEMATIC DIAGRAMS OF HYDRAULIC SYSTEMS

CHAPTER 2. SYSTEM DESIGN (cont'd)

SECTION 3. SYSTEM INSTALLATION REQUIREMENTS AND PRACTICES

1. GENERAL CONSIDERATIONS
2. ROUTING LINES AND INSTALLING COMPONENTS
3. LINE SEPARATION
4. INSTALLATION CLEANLINESS CONCERNS

SECTION 4. TITLE 14 CFR SECTIONS ON HYDRAULICS

1. COMPARING 14 CFR PARTS 23, 25, 27, AND 29
2. EVOLUTION OF HYDRAULIC SYSTEM REQUIREMENTS

CHAPTER 2. SYSTEM DESIGN (Cont'd)
Hydraulic Systems Regulations

- **Applicable 23/25/27/29 requirements in subparts A through G:**
  - **A: General**
  - **B: Flight**
  - **C: Structures**
  - **D: Design and Construction**
  - **E: Powerplant**
  - **F: Equipment**
  - **G: Operating Limitations and Information**

CHAPTER 2. SYSTEM DESIGN (Cont'd)
XX.1435, Overview

- **Main regulation for hydraulic systems, but not the only one (XX.1301, .1309)**
- **25.1435 paragraphs**
  - **(a) – element design**
  - **(b) – system design**
  - **(c) – tests**

CHAPTER 2. SYSTEM DESIGN
25.1435(a): Element Design

- **All hydraulic systems must have:**
  - **Fluid flowing through them**
  - **Reservoir to store fluid**
  - **Pump to move fluid**
  - **Actuating unit to convert fluid into a mechanical force to perform work**
  - **Flow control valves and pressure control valves to direct fluid flow and control system pressure**

CHAPTER 2. SYSTEM DESIGN
25.1435(a): Element Design (Cont'd)

- **Safety devices minimize loss of fluid and function:**
  - **Fuses**
  - **Shut-off valves**
  - **Relief valves**
- **Accumulators - energy-storage devices for back-up power and parking functions**

CHAPTER 2. SYSTEM DESIGN (Cont'd)
25.1435(a): Element Design (Cont'd)

- **Some aspects/factors to consider when reviewing design elements**:
  - **Design operating pressures in combination with limit structural loads**
  - **Proof and burst pressures**
  - **Fatigue and endurance life**
  - **Functionality with leakage**
  - **Duty cycles**

CHAPTER 2. SYSTEM DESIGN (Cont'd)
25.1435(b): System Design (Cont'd)

- **Intent - provide design, performance, and safety requirements for transport category airplane hydraulic systems**
- **Address aspects of component design and qualification, system/sub-system design, and system integration**
  - **Requires interfacing with engineers in numerous disciplines**

CHAPTER 2. SYSTEM DESIGN (Cont'd)

SECTION 5. DESIGNATED ENGINEERING REPRESENTATIVE (DER) FUNCTIONS

1. DUTIES WE AUTHORIZE DERs TO DO
2. DETAIL DESIGN AND INSTALLATION
3. EQUIPMENT QUALIFICATION TESTS
4. LIGHTNING/HIRF PROTECTION
5. SOFTWARE
6. SERVICE DOCUMENTS
7. MAJOR REPAIRS AND ALTERATIONS
8. SAFETY ANALYSIS

CHAPTER 2. SYSTEM DESIGN (cont'd)

SECTION 6. ASSESSING SYSTEM SAFETY

1. REASONS FOR ASSESSING SYSTEM SAFETY
2. FUNCTIONAL HAZARD ANALYSIS
3. PRELIMINARY SYSTEM SAFETY ASSESSMENT
4. SYSTEM SAFETY ASSESSMENT
5. COMMON CAUSE ANALYSIS
6. ASSESSMENT OF MODIFICATIONS TO PREVIOUSLY CERTIFICATED HYDRAULIC SYSTEM AND EQUIPMENT
7. MAJOR REPAIRS AND ALTERATIONS

SECTION 7. HUMAN FACTORS IN HYDRAULIC SYSTEMS

1. GUIDANCE ON HUMAN FACTORS FOR SYSTEM DESIGN
2. HUMAN FACTORS SPECIFICATIONS TO CONSIDER

CHAPTER 3. MANUFACTURING

1. GENERAL
2. APPLICABLE REGULATION REQUIREMENTS
3. APPLICABLE ORDERS

CHAPTER 4. TESTING

1. GENERAL
2. APPLICABLE REGULATION REQUIREMENTS
3. COMPONENT QUALIFICATION TESTS

CHAPTER 4. TESTING (CONT'D)

4. TYPES OF QUALIFICATION ASSURANCE TESTS

- **First Article Inspection Test**
- **Acceptance Tests**
- **Function Tests**
- **Qualification Tests**

5. REQUIREMENTS FOR EQUIPMENT LISTED IN AN SCD

6. CERTIFYING HYDRAULIC SYSTEMS

7. TYPES OF SPECIFICATIONS

8. COMPONENT-LEVEL, SYSTEM-LEVEL, AND AIRCRAFT-LEVEL TESTS

9. MEANS OF COMPLIANCE

10. ENDURANCE TESTS

CHAPTER 4. TESTING
25.1435(c): Tests

- **Testing of all parts of hydraulic system**
- **AC 25.1435-1, "Test conditions should be representative of the environment that the element, subsystem, or system may be exposed to in the design flight envelope"**

CHAPTER 4. TESTING
Iron Bird Tests

- **May use mockup of hydraulic system in lieu of flight tests where operating & environmental conditions do not affect validity of tests**
- **Recommend coordination between Systems & Structures engineers to validate ground-air-ground/ground cycle**

CHAPTER 4. TESTING
Proof Pressure Tests

- **On-airplane proof pressure test at relief valve setting shows:**
  - **Adequate separation between hydraulic system elements and structure**
  - **No permanent detrimental deformation to prevent system from performing its intended function**

CHAPTER 4. TESTING

Proof Pressure Tests (Cont'd)

On-airplane test of complete hydraulic system at relief valve pressure
(1.25 x operating pressure)

+

Component qualification bench testing at test pressure
(per FAR requirement for each component)

=

Level of safety equal to performing proof-pressure test in airplane

CHAPTER 4. TESTING
Ground and Flight Tests

- **Help verify hydraulic system performs its intended function**

- **Test**
  - **Normal flight conditions**
  - **Non-normal conditions (rejected takeoff)**
  - **Stall recovery**
  - **Simulated all engine out (ram air turbine op.)**

CHAPTER 4. TESTING (CONT'D)

11. ENVIRONMENTAL TESTS
12. PRESSURES, TRANSIENT PRESSURES, FATIGUE EVALUATION
13. FIRE PROTECTION
14. TESTS TO ENSURE PRODUCTS MEET 14 CFR PARTS 27 AND 29 REQUIREMENTS
15. PART 23 ADVISORY MATERIAL
16. DESIGN DATA AND DRAWINGS
17. MEANS OF COMPLIANCE CODES

CHAPTER 5. CERTIFICATION

1. GENERAL
2. TYPE CERTIFICATION PROCESS
3. APPLICABLE REGULATION REQUIREMENTS
4. DIFFERENCES AND SIMILARITIES BETWEEN REGULATIONS
5. COMPLIANCE CHECKLIST AND MEANS OF COMPLIANCE
6. CERTIFICATION ISSUES
7. EXTENDED RANGE OPERATION WITH TWO ENGINE AIRPLANES
8. FOREIGN AIRWORTHINESS REGULATIONS

CHAPTER 5. CERTIFICATION
29.1435 Versus 27.1435

- **Part 29 more detailed than part 27**
  - **For example, 29.1435 states that each hydraulic system using flammable fluids must meet applicable requirements of sections 29.861, .1183, and .1189**
  - **Part 27 does not include this requirement**

CHAPTER 5. CERTIFICATION INTERRELATIONSHIPS

	14 CFR Part 23 and Part 25 Subparts					
	B Flight	C Struct.	D Design	E Pwrplant	F Equip.	G OpsLim
Prop.	S	S	S	P	S	S
Mech. Systems	S	S	P	S	P	S
Elect. Systems	S	S	S	S	P	S
Structures	S	P	P	S	S	S
Flight Test	P	S	S	S	S	P
14 CFR Sections	XX.1 - XX.255	XX.301 - XX.581	XX.601 - XX.875	XX.901 - XX.1207	XX.1301 - XX.1461	XX.1501 - XX.1563

P = Primary Responsibility **S = Secondary Responsibility**

CHAPTER 6. INSTRUCTIONS FOR CONTINUED AIRWORTHINESS

1. REQUIREMENTS FOR PREPARING THE ICA
2. REGULATIONS ON ICA
3. OTHER APPLICABLE REGULATIONS
4. FAA ORDERS

CHAPTER 7. MAINTENANCE, PREVENTIVE MAINTENANCE, AND ALTERATIONS

1. GENERAL
2. APPLICABLE REGULATION REQUIREMENTS
3. REQUIREMENTS FOR MAINTENANCE AND INSPECTION, MAINTENANCE PROGRAMS ACCEPTANCE AND APPROVAL
4. FAA ORDERS
5. FAA ADVISORY CIRCULARS
6. MAINTENANCE OF HYDRAULIC SYSTEM COMPONENTS

CHAPTER 8. REPORTING REQUIREMENTS

1. GENERAL
2. APPLICABLE REGULATION REQUIREMENTS
3. HYDRAULIC SYSTEMS IN-SERVICE REPORTING AND CATEGORIES
4. AIRWORTHINESS DATABASES

APPENDIX 3. LESSONS LEARNED

- **Systems Review Task Force (SRTF) formed after DC-10 accident near Sioux City, Iowa, 7/19/1989, to review all wide-body hydraulic system designs**
  - **All hydraulics lost with one uncontained rotor burst - extremely improbable**
  - **ADs issued - install protective devices or hydraulic fuses at strategic location(s) to prevent complete loss of Hyd. fluid.**
  - **Lesson Learned: One of the most important requirements of an aircraft's hydraulic system is separation between the various systems. If systems have adequate separation between them, a single violent failure will not cause multiple hydraulic system failures.**

APPENDIX 3. LESSONS LEARNED (cont'd)

- **ENGINE FAILURE DAMAGE. On May 1, 1984, a Sikorsky S-76A helicopter made emergency water landing in the Gulf of Mexico. With 10 passengers and a crew of 2 aboard, the helicopter was inbound to shore from an oil rig when the pilot reported a loud bang. Then, the helicopter lost engine and electrical power, and smoke entered the cockpit and cabin.**

- **NTSB Recommended a review of the following:**

  1. All Certified Multiengine helicopters
  2. The probability that an uncontained engine failure will result in catastrophic damage to drive train and electrical, fuel and hydraulic system components and
  3. Required design changes

- **<u>Lesson Learned</u>. Ensure the hydraulic system has adequate protection from engine failure.**